CARBONIZATION STUDY OF NON-COKING COALS AND CHARACTERIZATION OF THEIR PROPERTIES FOR APPLICATION IN DRI PRODUCTION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology
In
Mechanical Engineering
(Specialization: Steel Technology)
By

Vasudev Singh Sengar

Roll No-213MM2488

Department of Metallurgical and Materials Engineering
National Institute of Technology, Rourkela – 769008

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Under the Guidance of

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CERTIFICATE

This is to certify that the Thesis Report entitled "Carbonization Study of non coking coals and characterization of their properties for application in DRI" submitted by **VASUDEV SINGH SENGAR** bearing roll no. **213MM2488** in partial fulfillment of the requirements for the award of Master of Technology in Mechanical Engineering with specialization in **"Steel Technology"** at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance .

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or diploma.

Place: Rourkela

Date 27/05/2015

Prof. M. Kumar

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Place: Rourkela

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ABSTRACT

There is scarcity of coking coal reserve in India. Only 15% coking coal is coking in nature. As Coking coal is costly, there arrives a need to find an alternative route for iron making. India is the world's biggest maker of DRI. The majority of which is delivered primarily through the coal based method of production. Growth in the DRI production can be attributed largely to the popularity of secondary steelmaking route, which has shown a phenomenal growth in India. This has been mainly because of the low investment cost of the Electric Arc Furnace (EAF) as compared to the integrated blast furnace-oxygen converter route and because of its better flexibility of product mix. The future of coal based sponge iron industry in India is bright because of huge availability of non –coking coal (85% of the total coal found). We are selecting different non-coking coal samples from various mines of Odisha to study and evaluate the effect of different carbonization temperatures on the physical, chemical properties, calorific value, reactivity, and caking index of the coal samples. . Present investigation deals with the study of physical and chemical properties of non- coking coal samples. The results indicated that the physical and chemical properties of coal depend on the carbonization temperature, heating rate and soaking time. It has been found that ash content and fixed carbon content increases while calorific value and volatile matter decreases as the carbonization temperatures rises from 400°C to 1000° C. It is also found that coal chars reactivity towards CO_2 decreases as the carbonization temperature rises from 400°C to 1000° C. Apparent porosity increases up to 400°C and decreases thereafter as the carbonization temperature increases up to 1000°C, while apparent density shows contradictory effect of apparent porosity. Lingraj coalmine showed higher fixed carbon content, calorific value and coal grade as compared to other coalmines. Reasons to carry out this work is to search good quality of coal for DRI plants.

Keywords: Carbonization, Non-coking coal, proximate analysis, calorific value, reactivity, ash fusion temperature, porosity

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Chapter1

Introduction

1.1Introduction:

Direct reduction (DR) is a process in which iron ore can be reduced to solid state either by solid or gaseous reducing agents. The solid-state DR process operate within a temperature range of 900°C-1100°C in order to prevent the formation of any semi fluid. [1] Non- coking coal or reformed natural gas is generally employed as the reductant as well as the primary source of energy. The final product from all DR processes is a solid, which can be melted during steel making in a manner similar to scrap. A large number of DR processes are available today, which can be grouped as follows:

- Coal based processes using rotary kilns.
- Coal based processes using other type of rectors like rotary hearth furnace, vertical retorts etc.

India produces 15.75million tones of DRI in 2006-07 while total DRI production of the world was 63.75million tones in 2006-07[2]. India is the world's biggest maker of DRI , greater part which is delivered mainly through the coal based system of production. Development in the DRI production can be credited largely to the prominence of secondary steelmaking route. DRI is a source of iron, which is relatively uniform in the composition and virtually free from tramp elements. It is used more and more in EAF and Induction furnace to reduce the contaminants present in the scrap used in these processes. It has an associated energy value in the form of combined carbon, which has a tendency to increase furnace efficiency. For captive DRI production facilities, there is an advantage that the delivery of hot DRI to the furnace reduces the energy consumption by 16 - 20%. The process of DRI manufacturing involves removal of oxygen from iron ore, due to which the departing oxygen causes micro pores in the ore body, turning it porous. Total no of DRI plants are more than 300 in India. Some of them are in Raigarh (C.G), Bellari, (karnataka), Odisha etc. The coal which is used in DRI plant, plays a very important role in the DRI production ,so the properties of coal such as reactivity, ash fusion temperature, calorific value, caking index, coal char strength, bulk density, porosity, swelling index, proximate analysis play very important role in the selection of coal for DRI plant. Majority of Indian coal has higher ash content and the major constituent of coal ash are $Al_2O_3$and SiO_2 .The presence of alkali oxides decrease the ash fusion temperature. Raw material constituents are 65-70% of the total cost of production of DRI. India is expecting production of 40MT of DRI by 2020. It is planned to increase the steel production up to 110 MT by 2025. In order to reach this goal, development, and implementation of DRI techniques is essential. Presently India has become World leader in DRI Production.

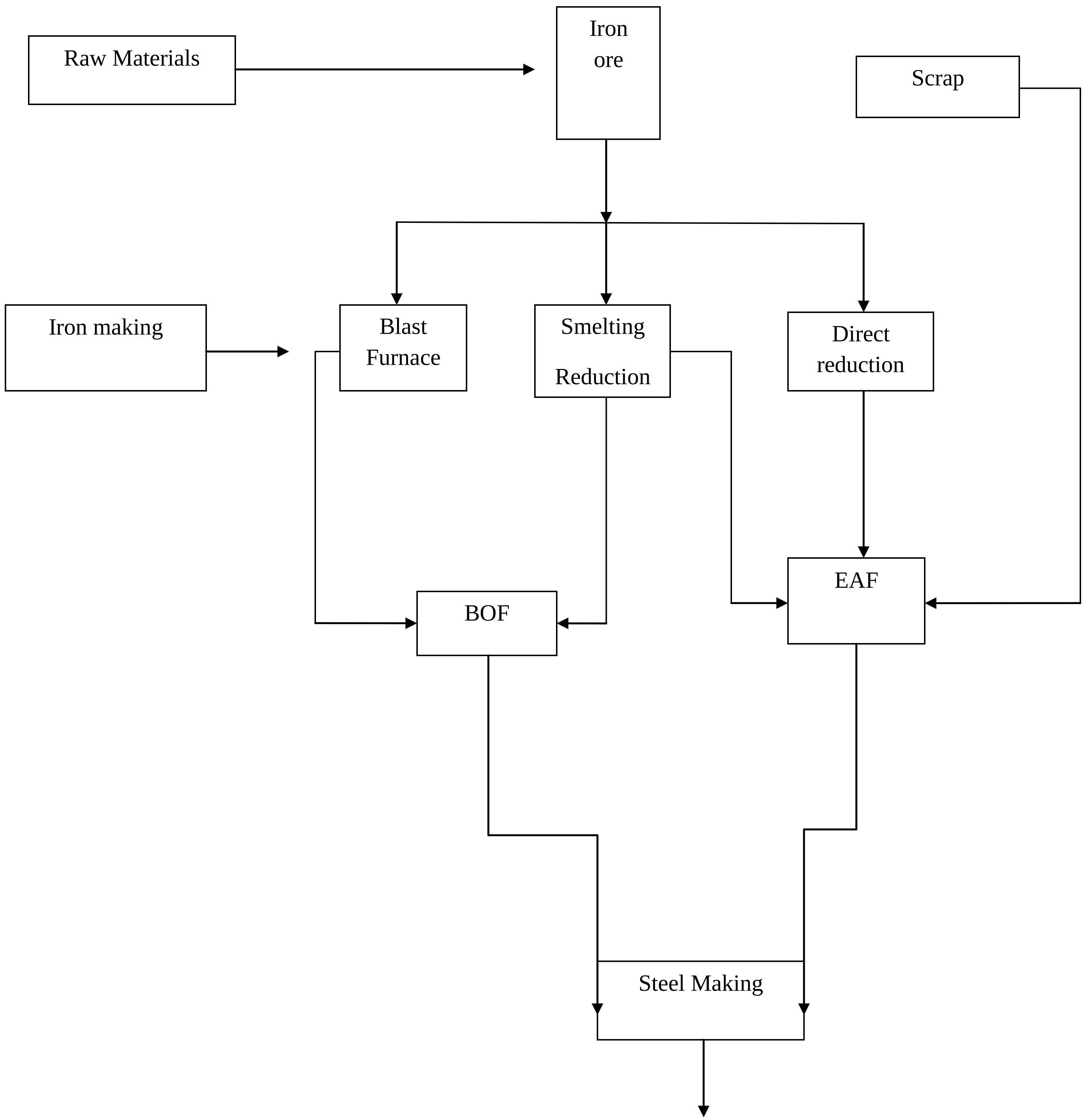

Fig 1.1: Block Diagram of Iron and Steel making process

1.2 Problems with conventional iron making (Blast Furnace):

1. Scarcity of coking coal reserve in India, only 15% of total coal is coking in nature.
2. High emissions of pollutants from iron Blast furnace
3. High investment cost involved in the construction of Iron blast furnace
4. Many repairs consumes a lot of time during the course of production

1.3 Categorization of alternative routes of iron making:

1.3.1 Use of low shaft furnace in which the strength of iron ore or coal or coke is not so important and hence non-coking coal or poor grade of coke can used as a fuel.

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1.3.3 Iron production by using Ferro coke

1.3.4 The smelting reduction or SR process

1.3.5 Iron production by the use of submerged electric arc furnace using a poor variety of coke, which acts as a reducing agent

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1.4.2 Higher productivity due tap-to-tap time is very short.

1.4.3 Low power consumption

1.4.4 Low electrodes consumptions.

1.4.5 Better metallurgical reaction

1.4.6 Refractory consumption is very low.

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1.4.9 The waste heat or hot gases generate during the process can be used for power generation.

1.5 Line diagram of different alternative methods of Iron Making:

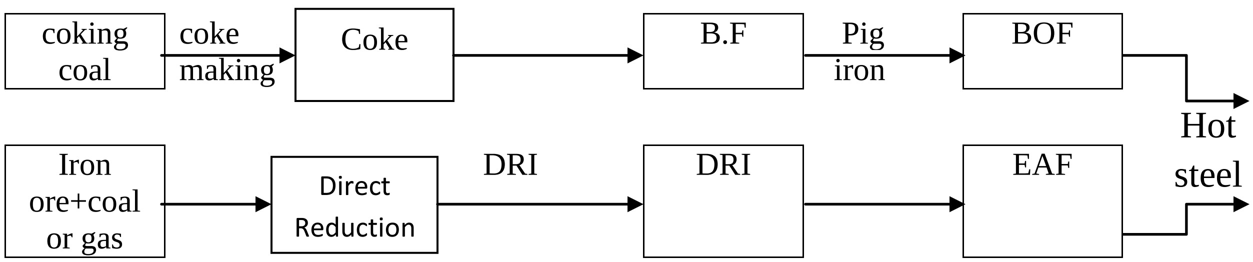


Fig 1.2

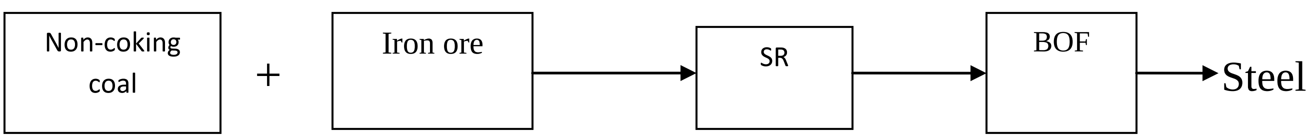


Fig 1.3

1.6 Factor affecting the selection of coal for DRI plant:

Following factors should be considered for the selection of coal for DRI plant.

i. Proximate and ultimate analysis of coal, proximate analysis calculate the value of moisture , volatile matter , ash and fixed carbon, For DRI plant fixed carbon present in the coal should have above 40% , volatile matter 28-32% and Ash content below25%

ii. Total carbon and hydrogen contents affect the gross calorific value of the coal as the content of total carbon and hydrogen in the coal increases the calorific value of the coal also increases.

iii. Reactivity of the coal towards CO2 also considered as the important parameter in the selection of coal for DRI plant. The value of reactivity should be above 1.7 ccof co/gm.sec for DRI because higher the value of reactivity more will be the reduction of iron ore.

iv. AFT plays a very important for the selection of coal in DRI plant i.e. Rotary kiln process. For DRI plant IDT and ST are very important, In general the IDT of coal ash should be at least 100°C more than the operation temperature in rotary kiln. Many of the DRI plants are using ST data should be at least 150°C-200°C higher than the operation of rotary kiln.

v. Calorific value is the ability of coal to convert the energy potential in to the heating ability. It plays very important role because it decides the grades of coal . The calorific value of the coal should be high because it fulfills the energy or heat requirement of the process.

vi. Caking index measures the sticking tendency of the coal. High Caking index of the coal produces jams by the formation of ring (agglomerate) inside the rotary kiln . So maximum value of caking index, which can be tolerated is 3.

vii. Bulk density affect the kiln productivity as well as transportation cost. As the bulk density, increases kiln productivity increases because more amounts of raw materials can be accommodated in a given volume of rotary kiln.

viii. Coal size is very important factor; in general, 6-15mmsize coal is used for concurrent charging and 1-10mm size for counter current feeding.

1.7 Grades of Indian coals:

Grades of Indian coal [3] .As shown in table (1.1)

Table (1.1)

Grades	Useful heat value (UHV) (Kcal / kg) UHV = 8900 – 138(A+M)	Corresponding (A+M) at 60% RH & 40° C	Gross calorific value (GCV) (Kcal / kg) at 5% moisture level
A	> 6200	≤ 19.5	> 6454
B	5601 − 6200	19.6 − 23.8	6050 − 6454
C	4941 − 5600	23.9 − 28.6	5598 − 6049
D	4201 − 4940	28.7 − 34.0	5090 − 5597
E	3361 − 4200	34.1 − 40.0	4325 − 5089
F	2401 − 3360	40.1 − 47.0	3866 − 4324
G	1301 − 2400	40.1 − 47.0	3114 − 3865

1.8 Coal reserves in India and world:

Estimated coal reserves in the world around 860billion tones while coal reserve in India as shown in table.[4]

Table 1.2: State wise coal reserves in India

Name of the state	Reserves in billion tone	% of total reserves
Odisha	75.07	24.89
Jharkhand	80.71	26.76
Chattishgarh	52.53	17.42
Madhya pradesh	25.67	8.51
West bengal	31.31	10.38
Maharastra	10.98	3.64
Andhra pradesh	22.48	7.45
Others	2.81	0.95

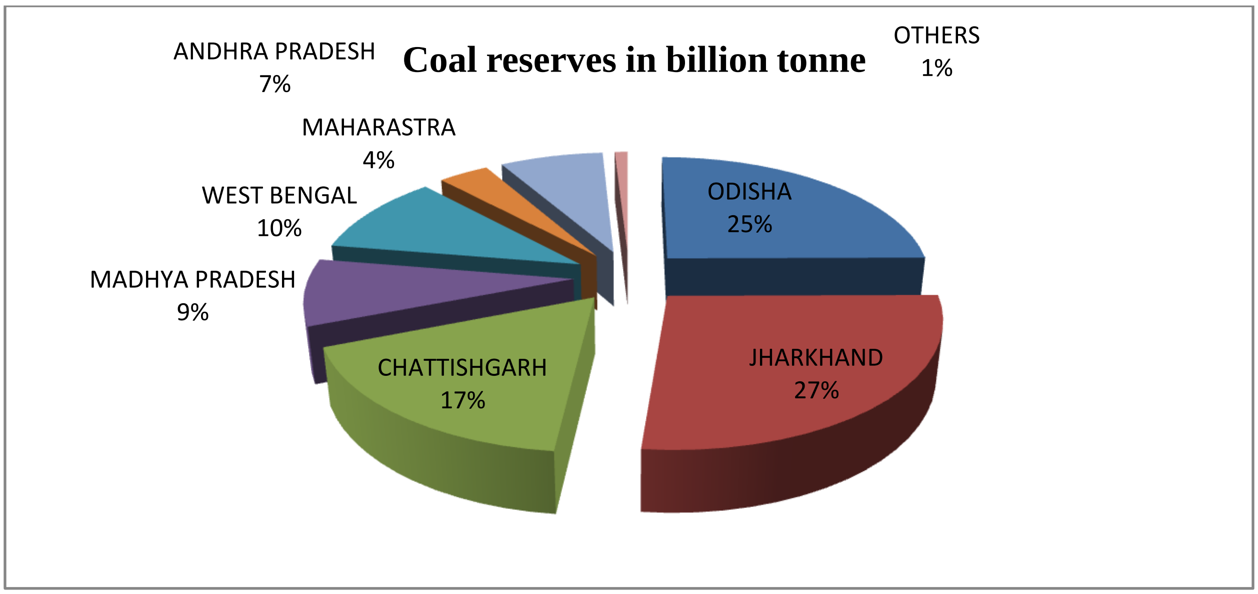


Fig 1.4: Coal reserves in India

1.9 DRI production in India and world by processes:

Though Majority of the sponge iron in the world is produced by gas-based process, but coal based processes are more important for India, because of huge deposits of coal and scarcity gas.

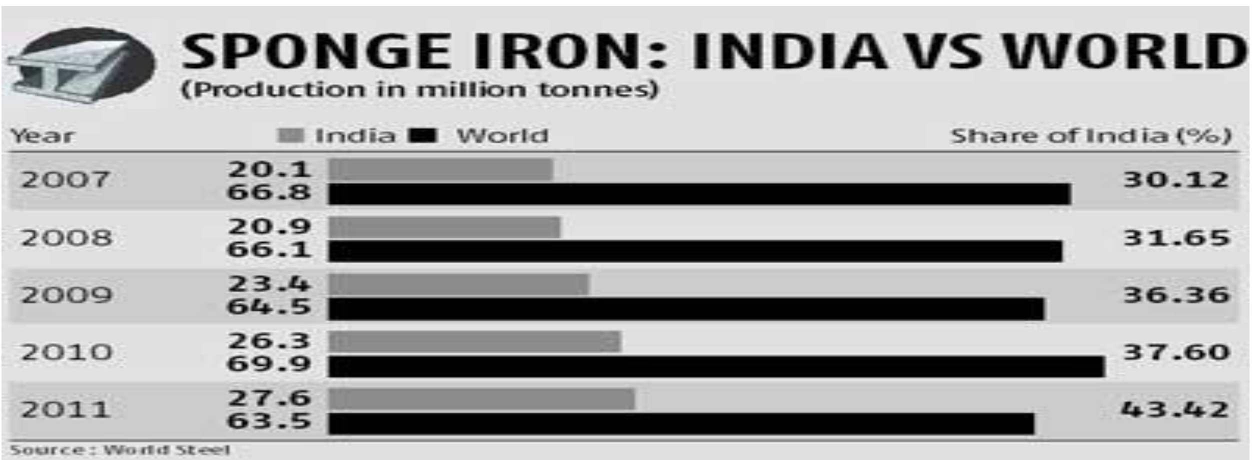


Fig 1.5(source world steel)[5]

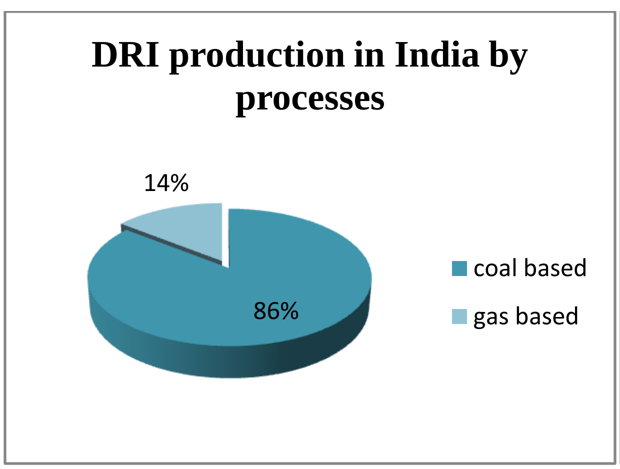


Fig 1.6 (a)

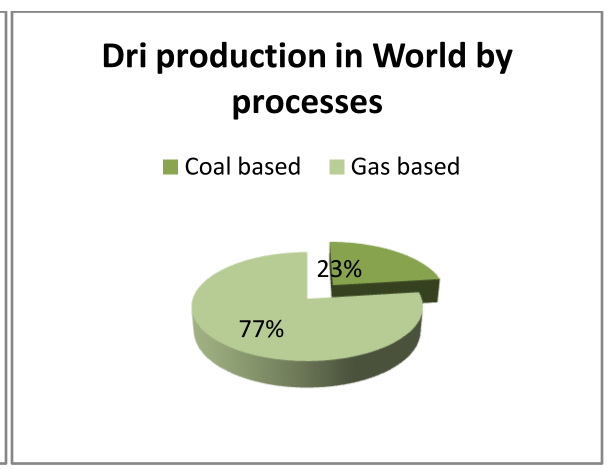


Fig1.6 (b)

1.10: Flow Diagram OF Rotary Kiln DRI production

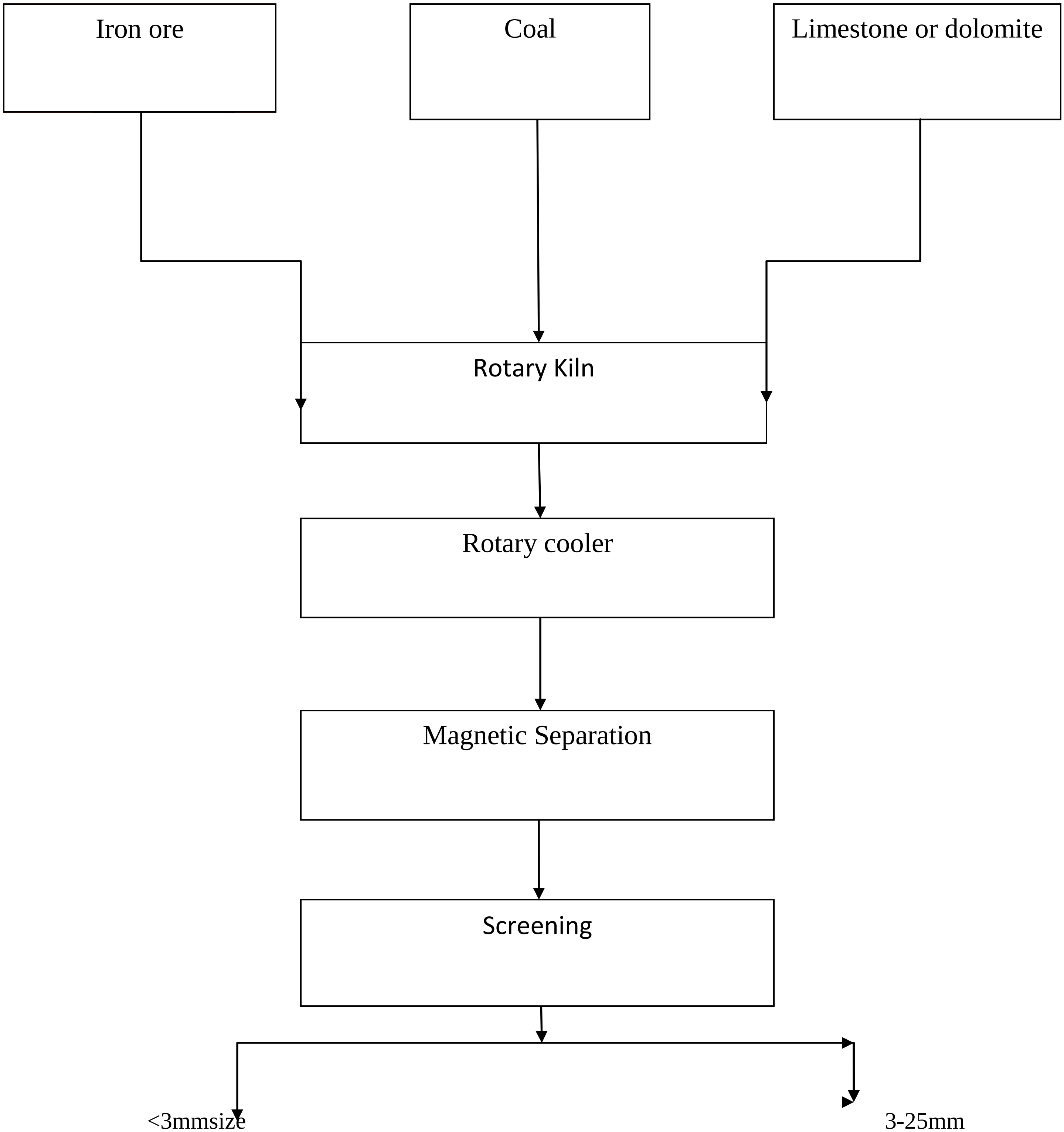


Fig 1.7: Flow Diagram OF Rotary Kiln DRI production

1.11 Coal quality requirements for DRI Plants:

Coal quality requirements for sponge iron plants shows in table 1.3 [6]

Table 1.3: coal quality requirements for DRI plants

S. N	Coal characteristics	Requirements
1.	Total Moisture content at 60% RH & 40^0 C by mass(%)	6
2.	Grade	B or C
3.	UHV kcal/kg	4940-6200
4.	Fixed carbon	Above 42
5.	Volatile matter	Above30
6.	Ash content	22-25
7.	Reactivity(cc of CO per gm of c sec)	above1.7
8.	Size(mm)	-25+3
9.	Initial deformation Temperature	Above 1280

Chapter 2

Literature Review

Shaobo Sen et. al (2012)worked on the Effective removal of sulfur from high-sulfur coal prior to use by dry chlorination at low temperature and they observed that the removal of sulphur is greatly affected by the chlorination temperature and particle size, they investigated under the optimal condition (350°C sulphur content in the chlorinated coal was 1.12 wt%). High proportion of inorganic sulphur, pyrite sulphur and organic sulphur were removed by the use of dry chlorination. [7]

Kumar and Patel (2008) were working on the characterization of non-coking coals collected from various coalmines of Odisha. They observed that sulfur content (extend .40-.66) is not an issue. They also obtained Maximum number of coalmines have no caking qualities. Coal ash of maximum number of coal mines were observed to have high ash fusion temperatures (IDT>1100, ST>1349, HT>1500, FT>1500). The final result indicated that when the increment of fixed carbon occurred in the chars, reactivity of the coal char decreases towards CO2. Maximum numbers of coal chars have high reactivity (greater than 4cc of co/gm.sec).[8]

A.K Majumdar et. al (2008) proposed a new method to determine the HHV by the use of proximate analysis of the samples, because the measurements of HHV is costly and required skilled operator to calculate the HHV, while proximate analysis is very easy and low costly process. They tried to present simple model based on Proximate analysis of coal samples. They analyzed around 250 Indian coal samples and presented a simple model including all the factors which affect the HHV of coal samples in calculating the value of HHV by proximate analysis. The correlation is given by the following relationship [9]

$$HHV = -0.03(A) - 0.11(M) + 0.33(VM) + .35(FC)$$

Kumar and Gupta(1994) studies the carbonization of non-coking coals collected from Dhanbad coal mines. The analysis of result showed that as the carbonization temperature increases from 400°C to 1000°C expulsion rate of gases increases from the coals, due to this reason volatile matter decreases ,hydrogen content also decreases continuously. As the hydrogen content decreases, calorific value also decreased. The reactivity of coal chars decreases towards CO_2 as the carbonization temperature increases. True density increases with increasing in carbonization temperature while apparent density slightly decreases up to 400°C after that increases continuously. [10]

Raymond C. Everson .et. al worked on the combustion and characterization of the coals. They found that the presence of low porosity in the char indicates the presence of the high intertinite in the coal (collected from South African mines). [11]

Kumar et. al.(2008) worked on the reduction behavior of iron ore for DRI plant and t observed that in first 30 minutes, the degree of reduction was more intense after that it became slow. They also found that slow heating rate led to higher degree of reduction as compared to the rapid heating rate [12]

Kumar and Gupta(1994) worked on the relationship between the properties of wood char and reactivity and suggested that as carbonization temperature and soaking time increases reactivity decreases. Chars prepared under the condition of high heating rate (30c/min) were observed to be more reactive as compared to that of slow heating rate (4c/min). [13]

T.R Ramchandra Rao(2006) research deals with the direct reduced iron industry .He suggested a way to overcome the raw materials related problems for direct reduced iron plants by use of pellets in place of lump can increaseses the production of DRI and better utilization of raw materials. [14]

Arpita Shrma et.al (2014) studied the physic chemical properties and Major minerals and oxides present in the ash of the coals samples collected from Meghalaya. They analyzed the effect of oxides towards the AFT. They observed that if the concentration of SiO_2 increases, the value of IDT decreases. While if the concentration of Al_2O_3 increases, the value of IDT moderately increases. Oxides like CaO ,MgO and Fe_2O_3 and alkalis may reduce the IDT. They also investigated that slag formation is disturbed if the concentration of basic oxides is less than that of acid oxides.[15]

B.C Kim investigated the coal characteristics at different carbonization temperature and noted various conclusions about the coal carbonization. He observed that reactivity of coal char decreases when the carbonization temperature increases. At higher temperature, gasification was reduced due to the decrement in the number of active carbon sites. This effect mainly appears in low rank of coal [16]

D.D Haldar (2010) was worked on the beneficiation process of non coking coals and he presented the importance of beneficiation process as it improved the properties of non coking coal, such as calorific value, char characteristics, volatile matter. He suggested that if beneficiation is used, it imparts qualities in the coal which is required for the selection of coal for the iron making plants . During beneficiation particles of coal cleans up and regains the properties, which is required in iron making plant.[17]

Bo Liu .et .al (2013) analyzed the 34 synthetic ash and determined in a atmosphere of carbon and present the correlation between the AFT and chemical composition of ash present in the coal because AFT plays very important role in the selection of coal for DRI plant. They analysed and observed that as the Fe_2O_3 content and S/A ratio increases the AFT of the coal sample decreases and AFT is not affected with the variation in K_2O content in coal ashes. They suggested that the conclusions obtained from 34 synthetic ashes are also applicable to 17-coal ashes procured from various places.[18]

A. Marcilla. et. al (1996) studied the influence of carbonization step heating rate on the properties of sub bituminous coal, at a slow heating rate (5kalvin/min) and high heating rate 100 Kelvin/sec and also studied various types of carbonization processes by combination of slow heating rate and very high heating rate and they observed that the chars obtained from slow heating rate shows lower reactivity and the chars obtained from a high heating rate showed high reactivity. [19]

N.Y Kirov and M.A Peck (1970) worked on the characterization of char produced in the temperature range of 425-800°C by the carbonization of coal, and developed the relationship between the volatile matter , hydrogen content and carbon content of the chars and carbonization temperature are described by the use of batch fluid bed technique. They analyzed that as the carbonization temperature increases volatile matter decreases hydrogen content also decreases while carbon content increases with the carbonization temperature.[20]

Mamoru Kamishita .et al (2008) studied the result of deposition of carbon on reactivity and porosity of a lignite char .They observed that due to splitting of CH_4, the deposition of carbon in to the pores of the lignite chars occured at an considerably rate at the temperature of 815°C and 850°C. The amount of carbon deposition is much lower than the available volume of open pores for carbon. Acid washing which removes the inorganic impurities reduces the extent of carbon deposition., surface area and open pore volume reduces by the deposition of carbon. They suggested a method to maximize the reactivity by minimum deposition of carbon from volatiles when the coal is converted in to the char.[21]

Chapter 3

Objectives

Objectives of current project work:

i. To determine the proximate analysis of coal samples collected from different mines of Odisha
ii. To analyze and evaluate the calorific or heating value of the all the coal samples collected from different mines of Odisha.
iii. To analyze and calculate the AFTs of all the coal mines.
iv. To estimate the reactivity of all the coal chars samples towards the CO_2
v. To evaluate the apparent porosity and apparent density of all the coal samples
vi. Carbonization analysis of all the coal samples selected from different mines of Odisha
vii. To study the effect of soaking time on the coal characteristics
viii. To assess the effect of variation in heating rate of all the selected coal samples
ix. To detailed analysis of all the results found from various experiments and search a good quality of coals for the DRI plants

Chapter 4

Experimental Investigation

4.1 Selection of materials:

We selected the coal samples from five different mines of Odisha, namely Bharatpur coalmine, Basundhra coalmine, Jagannath coalmine, Lingraj coalmine, and Brajraj Nagar coalmine.

Fig 4.1(a): Coal powder **Fig4.1 (b): Lumpy coal**

4.2 Proximate Analysis of coals:

Proximate analysis determines the presence of moisture, volatile matter ash content and fixed carbon in the coals. The procedure to determine the above parameters as per the Indian standard method [22] is given below.

4.2.1 Procedure to determine the moisture content :

1. About 1gm of air-dried -212 micron coal sample is placed inside the crucible and kept in the furnace at the temperature of 105°C-110°C for one hour
2. After one hour, sample was taken out from the furnace.
3. The weight loss in the coal sample expressed as the moisture content present in the coal sample
4. Moisture content is calculated by the following formula

$$\text{Percentage of moisture} = \frac{X-Y}{X}$$

Where, X is the initial weight and Y is the final weight of the coal sample

4.2.2 Procedure to determine the volatile matter content:

1. About 1gm of air dried -212 micron (-72 mesh size) coal sample is kept in a silica crucible and placed in the furnace and is maintained at 925°C-950°C for 7 minutes
2. After seven minutes, sample was taken out from the furnace.
3. Calculate the volatile matter by using the following relationship

$$\text{Volatile Matter content (\%)} = \frac{\text{Loss in weight}}{\text{Initial weight}} * 100 - \text{Moisture content(\%)}$$

4.2.3 Procedure to determine the ash content :

1. About 1gm of air-dried -212 micron (-72 mesh size) coal sample is kept in a silica crucible and placed in the furnace and is maintained at 775°C-780°C, until the complete burning of the sample, normally it takes around one hour.
2. After complete burning, the coal sample was taken out from the furnace.
3. Calculate the Ash percentage by using the following relationship

$$\text{Ash content (\%)} = \frac{\text{Weght of residue}}{\text{Initial weight}} * 100$$

4.2.4 Calculation for the fixed carbon content:

Fixed carbon is determined by the following relationship

Fixed carbon (%) = 100 - (M + VM + A)

Where

M= % of Moisture content

VM= % of Volatile matter content

A= % of Ash content

4.3 Procedure to determine the Energy or Heating value/ Gross calorific value:

Energy or Heating value/ Gross calorific value of the selected coal samples is determined as per the Indian standard method by the use of bomb calorimeter as shown in fig [23]. Before starting the experiment a briquetted coal sample, around 1 gm is prepared and is placed in the furnace for the drying purposes. Now the sample was set in the bomb. A cotton thread around fifteen cm long is in the contact with the sample, Now the oxygen gas was passed at the pressure of 25-30atm. After that the bomb was set in the water filled bucket that was joined with the source of power for ignition. Now the briquetted coal sample was combusted in the presence of oxygen gas. As the value of temperature increases was noted in every minute until the temperature reaches to its maximum value. The given relationship adopted to measured the GCV of the coal

$$\text{Gross calorific value} = \frac{[\{WE * (\Delta T + .04)\}]}{W}$$

Where

WE = Water equivalent (1987kcal/°C)

ΔT= Temperature difference maximum to minimum value

W= Weight of the briquetted samples

Fig 4.2 (a): Oxygen bomb Calorimeter **Fig4.2 (b): Briquetted coal sample**

4.4 Procedure to determine the apparent porosity and apparent density:

A specimen of coal of 10-15 mm size was dried in the furnace in the temperature range of 105°C-110°C and weight of this dried specimen was measured. The dried specimen was hanged in a hot boiling water through a thread and a metal stand. The specimen was kept in hot water for 20 minutes. At that point the hanged weight of the specimen+ thread while immersed in water was measured by a chemical balance. The specimen was then expelled from thread and the weight of the thread while immersed in water was measured. At a final point, the weight of water-saturated specimen was measured in air.[24]

We can the use of following relation to calculate the apparent porosity and apparent density, of the selected coal samples.

$$\text{Apparent porosity} = \frac{(W-D)}{\{D-(S-s)\}}$$

$$\text{Apparent density} = \frac{D}{\{D-(S-s)\}}$$

Where

D = Dried weight of coal specimen

W = weight of water saturated sample in air

S = suspended weight of sample + thread while immersed in water

s = suspended weight of thread only while immersed in water

4.5 Procedure for the determination of coal chars Reactivity:

It is the measure of the ability of coal char to react with CO2 to form CO gas by the reaction

$$C + CO2 \longrightarrow 2CO\text{-(Endothermic reaction)}$$

Reactivity was determined as per the Indian standard [25].To start reactivity measurement first of all prepare a coal char at the temperature 925°C -950°C for 2 hours after coal char preparation, determine the proximate analysis of coal char . A representative sample of 5 gm of .5 to 1mm size was placed in the quartz tube sealing both ends of the sample by either quartz wool or a 200 mesh circular screen made of stainless steel. The tube was placed in the furnace in such a way that the sample was in the uniform temperature zone. Now nitrogen is passed at the rate of 50c.c per minute and the test sample is preheated to 1000 ±5°C , as the temperature is stabilized carbon die oxide is passed at the rate of100cc for 25 minutes as the 25 minutes completed the flow of CO_2 stopped and in place of CO_2, nitrogen gas is passed at the rate of 50cc per minute until the temperature of reacted samples was brought down to150°C . Care should be taken while passing nitrogen gas such that no ash is blown off from the quartz tube.

The remaining sample is then weighted after transferring it carefully from the quartz tube to suitable containers.

Formula

$$\text{Reactivity} = \frac{11.61 * W}{(5 * Cfix - \frac{W}{2})}$$

Where, W = weight loss

C_{fix} = fixed carbon content of the char.

4.6 Procedure for determination of Ash Fusion temperature (AFT):

AFT was determined as per the Germen standard[26]. A Cube was made from 3-4mg of ash powder of the selected coal samples and is heated in a sophisticated furnace fitted with a microscope. During heating , the changes in shape and size of the cube are recorded regularly with the help of the microscope. The temperature at which the shrinkage appears in the cube is called IDT, the temperature at which rounding of the corners of the cube appears is recorded and is called softening temperature (ST). The temperature at which the cube becomes semi flow and get the shape of a semi sphere is recorded and is called HT, the temperature at which cube becomes completely fluid and speared over the surface is recorded, this is nothing but FT.

Fig 4.3 (a): Leitz Heating microscope

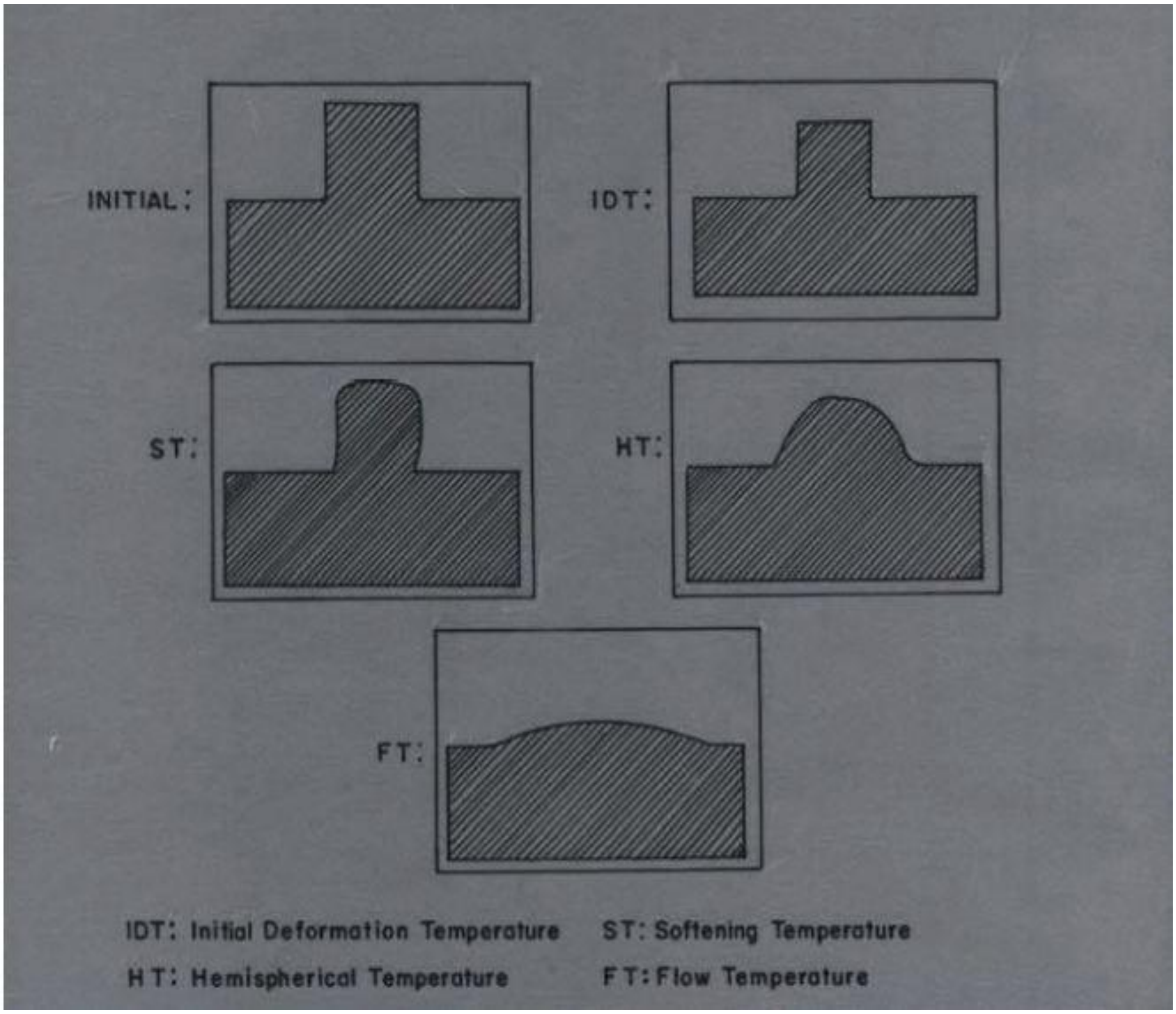


Fig 4.3(b): Variation in the shape of the ash sample with temperatures

4.7 **Procedure for determination of caking Index:**

Caking index was determined as per the Indian standard [27].Coal samples powder and sand Powder was mixed in different amount in such a manner that the total weight of the mixture is always 25gm. The mixture was kept in the crucibles and placed in the furnace maintained at a temperature 925°C-950°C. Crucible was soaked at this temperature for 7 minute only and then removed from the furnace. After that a weight of 500 gm is placed on each of the cake formed, fines will be generated, measured the weight of fined produced from each cake. The cake for which the weight of the fines generated is less than 1.25gm (i.e. less than of 5%) total is selected for caking index determination.

4.8 Carbonization Process:

Carbonization means heating of carbonaceous material in the absence of air or in an inert atmosphere in order to meet the requirements or improvements in the properties such as higher fixed carbon, improvements in mechanical strength, density, and carbon- carbon bond strength.

4.8.1 Procedure for carbonization of non-coking coals:

Air dried coal sample of 20gm was placed in the furnace, to attain the various carbonization temperature(400°C,600°C,800°C,1000°C) with soaking time (60min and 120 min) respectively. Selected Coal samples were placed in a steel box and this box was kept in the muffle furnace to attain the required carbonization temperature 400°C -1000°C. When the coal samples attain the required carbonization temperature, sample was taken out from the furnace and determines the proximate analysis of that coal chars.

Chapter 5

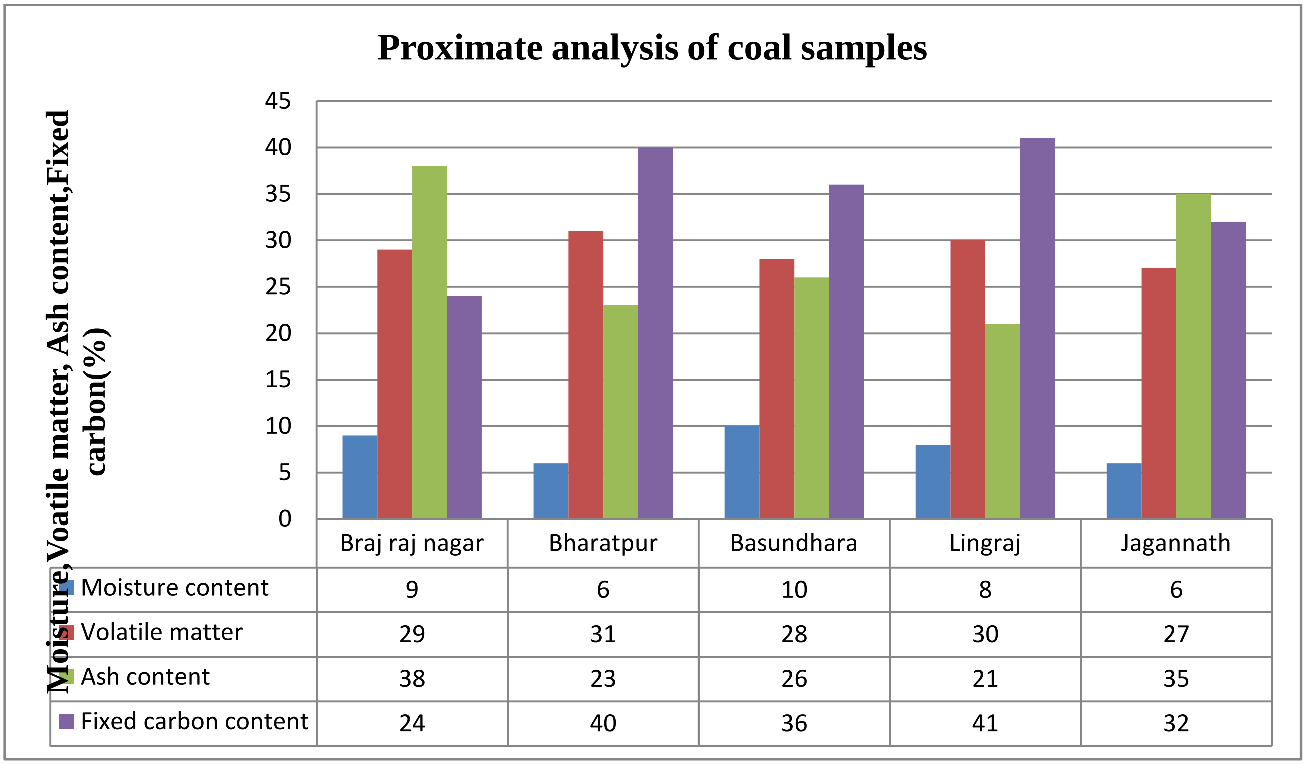
5 Results and discussions

5.1 General characteristics of selected coal samples:

Coal characteristics plays very important role in the rotary kiln operation because of its properties such as proximate analysis, apparent porosity and apparent density, reactivity calorific value, caking index, ash fusion temperature, provided the information about the various factors which is required for the smooth and continuous kiln operation during the reduction of iron ore. During the reduction of iron, ore fixed carbon content provided the information about the availability of carbon. Proximate analysis provided information about the moisture content, volatile matter content, ash content and fixed carbon content as illustrated in table no (5.1). Proximate analysis results showed that the fixed carbon, volatile matter, ash content and moisture content was in the range of 24%-41%, 27%-31%, 21%-38% and 6%- 10% respectively. Lingraj coalmine showed the highest fixed carbon content and calorific value among all the coalmines. Among all the coal samples Bharatpur and Lingraj coal samples are most suitable for DRI plants because they full fill the requirements of DRI plant.

Table5.1: Proximate analysis of the selected coal samples

Coal mines	Proximate analysis (wt %)			
	Moisture content	Volatile matter	Ash content	Fixed carbon content
Brajraj nagar	9	29	38	24
Bharatpur	6	31	23	40
Basundhara	10	28	26	36
Lingraj	8	30	21	41
Jagannath	6	27	35	32



	Braj raj nagar	Bharatpur	Basundhara	Lingraj	Jagannath
Moisture content	9	6	10	8	6
Volatile matter	29	31	28	30	27
Ash content	38	23	26	21	35
Fixed carbon content	24	40	36	41	32

Fig 5.1: Variation of proximate analysis of different mines of Odisha

5.2 Reactivity of coal chars towards the carbon dioxide:

It is the measure of the ability of coal char to react with CO_2 to form CO gas by the reaction

$$C + CO_2 \longrightarrow 2CO \text{ - (Endothermic reaction)}$$

Reactivity plays a very important role in the rotary kiln operation because higher reactivity of coal char allows the kiln operation at lower temperature which reduces the chances of ring formation inside the rotary kiln and also reduces the energy consumption in the rotary kiln.. Reactivity of all the coal char samples were calculated and it was observed that the reactivity of all the selected coal chars in the range of 2.97-5.23 (CC of CO/gm . sec.) which is higher than the required reactivity for DRI plant. Generally As the fixed carbon content increases reactivity of coalchar decreases.

Table 5.2: Reactivity of all the coal chars

Mines name	Reactivity(CC of CO/gm . sec)
Brajraj nagar	5.23
Bharatpur	5.12
Basundhara	3.89
Lingraj	3.38
Jagannath	2.97

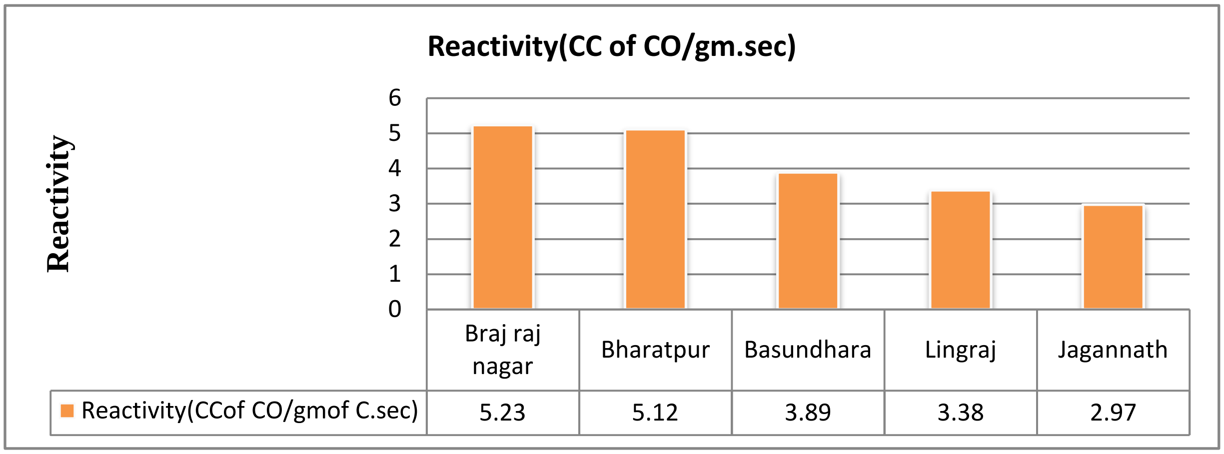


Fig 5.2: Variation of reactivity of all the coal samples

5.3 Heating value or calorific value:

Calorific value is the ability of coal to convert the energy potential in to the heating ability.

Heating value or calorific value of all the selected coal samples were determined and it was observed that the calorific value of all the coal samples in the range of 3610.52-5542.27 Kcal/kg. It observed that Lingraj coalmine has higher calorific value as compare to other coalmines. It is also observed that all the coalmines showed ,category of low grades (DEF)

Table: 5.3Calorific value of different coal samples

Mines name	Gross calorific value(GCV) Kcal/kg
Brajraj nagar	3610.52
Bharatpur	5484.12
Basundhara	4828.45
Lingraj	5542.27
Jagannath	3728.89

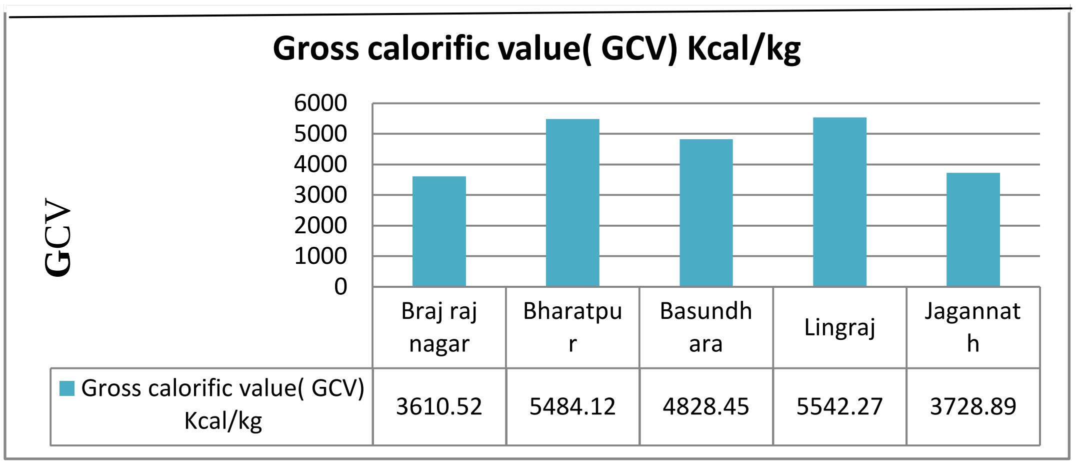


Fig 5.3: variation of GCV of all the coal samples

5.4 Apparent porosity and apparent density:

Porosity connected with the reactivity of the coal char, if the coal have the higher porosity, then the higher surface area available for the coal to expose the oxidizing gases from the coals, which increases the reactivity of coal, hence better reduction of iron ore

Table 5.4: Apparent porosity and apparent density of the selected coal samples

Mines name	Apparent porosity (%)	Apparent density
Brajraj nagar	36.82	1.328
Bharatpur	34.31	1.377
Basundhara	31.03	1.427
Lingraj	28.07	1.49
Jagannath	25.28	1.60

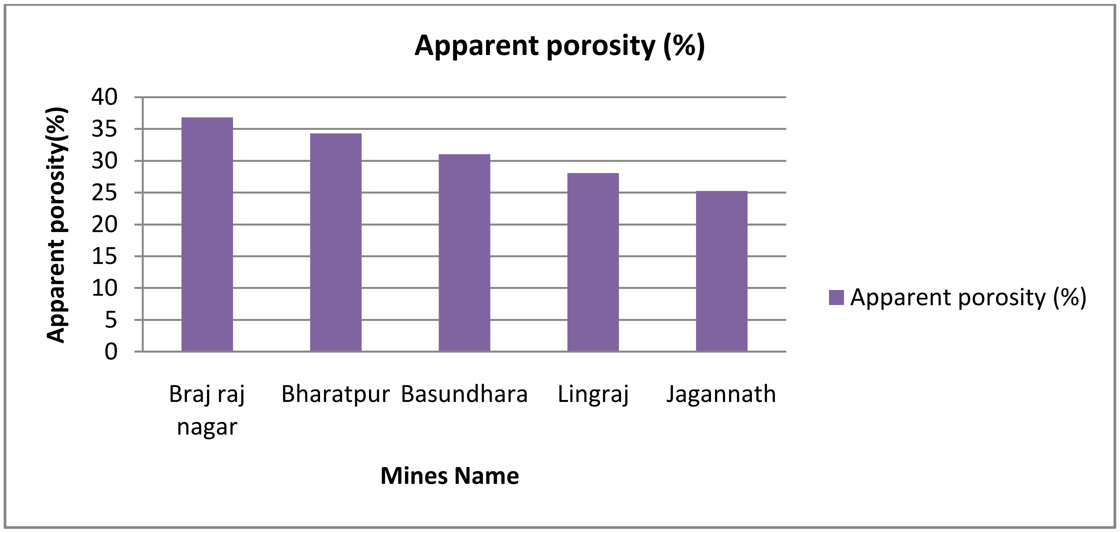


Fig 5.4 : Variation of apparent porosity of all the coal samples

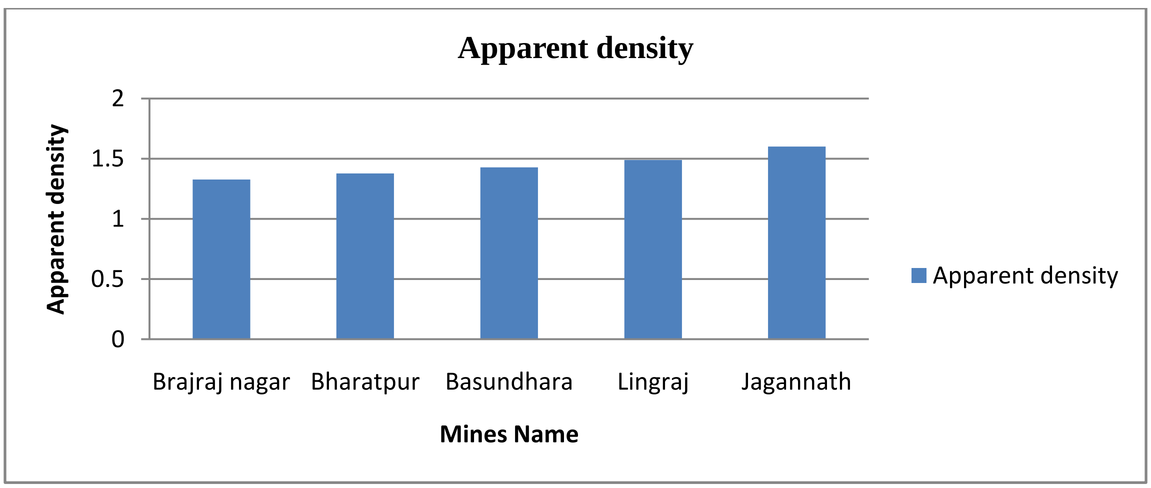


Fig 5.5 : Variation of apparent density of all the coal samples

5.5 Caking index:

Caking properties of coal means the measurement of sticking tendency. As the caking index increases, the sticking of particle increases. Using of high caking coal in rotary kiln is increases the formation of ring and ultimately jams inside the rotary kiln ,this will stop the rotary kiln operation .For the use of coal in rotary kiln the caking index of the coal should be below 1, however it can be tolerated up to 3. It is observed that almost all the coalmines except Basundhara have no caking index as shown in the table 5.6.

Table5.5: Caking index of selected coal mines

Mines name	Caking index
Braj raj nagar	Nil
Bharatpur	Nil
Basundhara	2.1
Lingraj	Nil
Jagannath	Nil

5.6 Ash fusion temperature:

Ash fusion temperature is a very important parameter because it is a measurement of ash fusibility of the coal samples. It provides the knowledge about the ring formation inside the rotary kiln. , In general the IDT of coal ash should be at least 100°C more than the operation temperature of rotary kiln. Under mild reducing condition the value of IDT can decreased by 50°C-80°C, hence all the experiments of assessing coal suitability in direct reduced kiln should be carried out in reducing atmosphere. If the ash fusion temperature has low value it increases the sticking of particles and ultimately ring formation inside the rotary kiln, increases the energy consumption inside the rotary kiln hence reduction in kiln productivity.

Effect of various constituents of ash in the order of increasing the value of AFT

as the Effects of TiO_2 > the effect of Al_2O_3 > the effects of SiO_2 > the effect of K_20 and the effect of various constituents of ash in order of decreasing the value of AFT

Effects of SO_3 > the effect of CaO > the effects of MgO > the effect of Fe_2O_3

Table 5.6: AFT of all the coal ashes

Mines name	Ash Fusion temperature (AFT)°C			
	Initial deformation temperature (IDT)	Softening temperature (ST)	Hemispherical temperature (HT)	Fluid temperature (FT)
Bharatpur	1207	1256	1367	1440
Basundhara	1189	1392	1490	1561
Lingraj	1164	1369	1478	1544
Jagannath	1227	1491	1555	1597

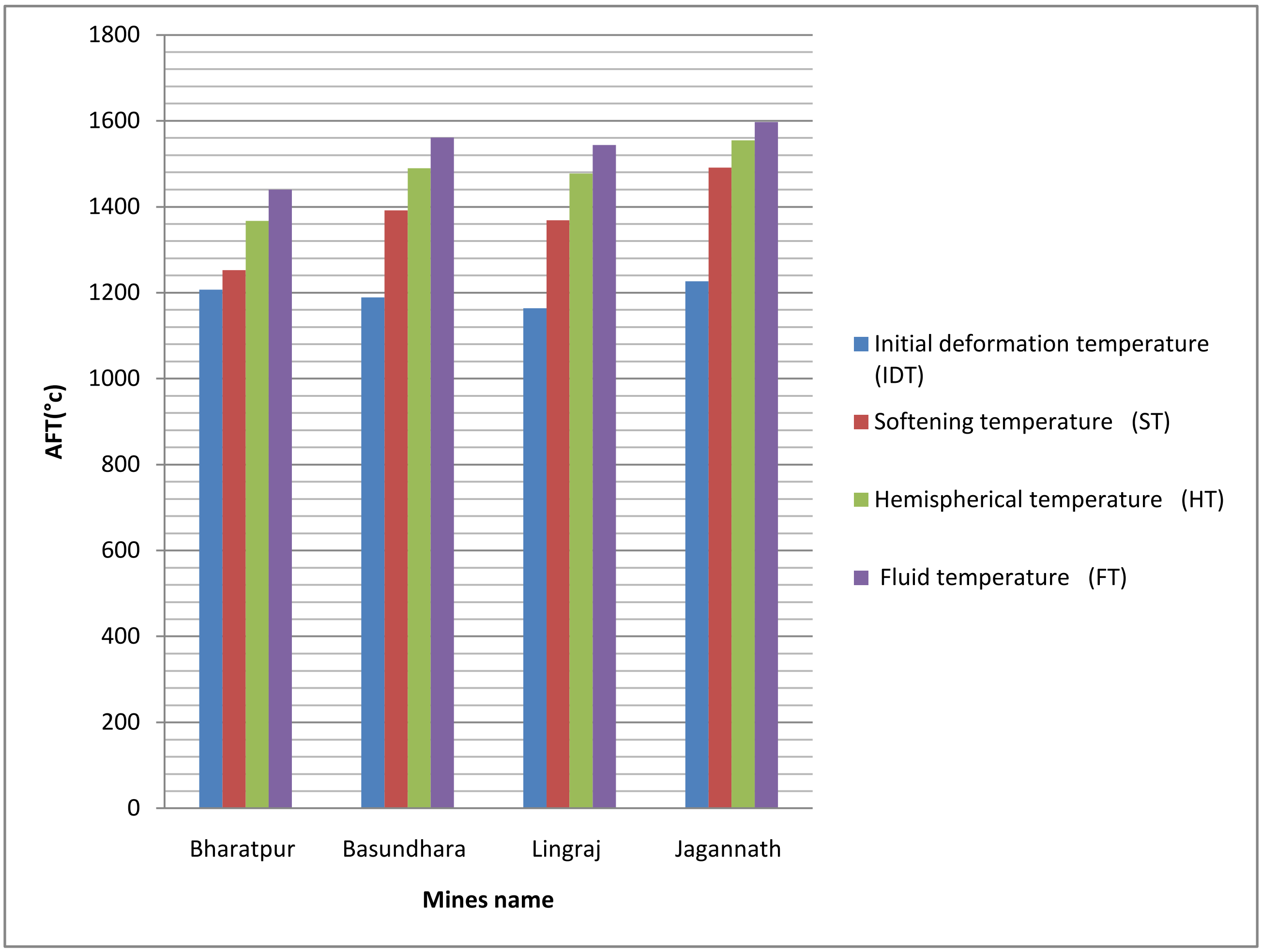


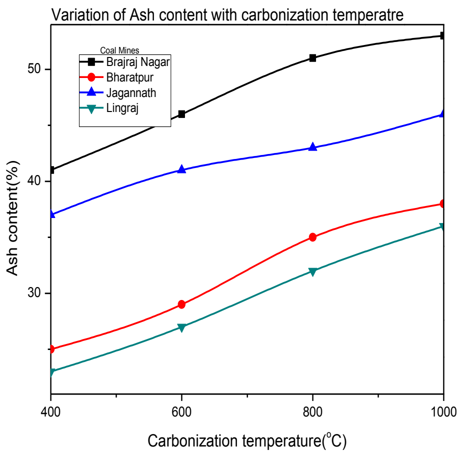
Fig 5.6: Variation of AFT of the coal ashes

5.7 Carbonization of non- coking coal:

Heating of the coal in the absence of air is called coal carbonization. Carbonization is used to increase the carbon content in the coal, as the carbonization temperature increases from 400°C - 1000°C fixed carbon and ash content increases while the volatile matter decreases because the rate of the escaping of the gases increases hence the volatile matter decreases. When the carbonization temperature increases from 400°C- 1000°C the reactivity of coal char decreases.

Table 5.7: Effect of carbonization temperature on the properties of coals chars

Coal Mines	Carbonization temperature (°C)	Carbonization time	Proximate analysis (wt. %)				Reactivity (cc of CO/gm.sec)
			Moisture content	Volatile matter	Ash content	Fixed carbon content	
Brajraj nagar	400	1hr	7	23	41	29	5.53
	600		5	14	46	35	5.44
	800		2	8	51	39	5.32
	1000		1	2	53	44	5.11
Bharatpur	400	1hr	5	28	25	42	5.37
	600		3	18	29	50	5.31
	800		2	8	35	55	5.19
	1000		nil	2	38	60	4.98
jagannath	400	1hr	4	21	37	38	3.41
	600		2	10	41	47	3.27
	800		1	5	43	51	3.06
	1000		nil	1	46	53	2.91
Lingraj	400	1hr	6	27	23	44	3.72
	600		4	16	27	53	3.57
	800		2	9	32	57	3.42
	1000		nil	2	36	62	3.32



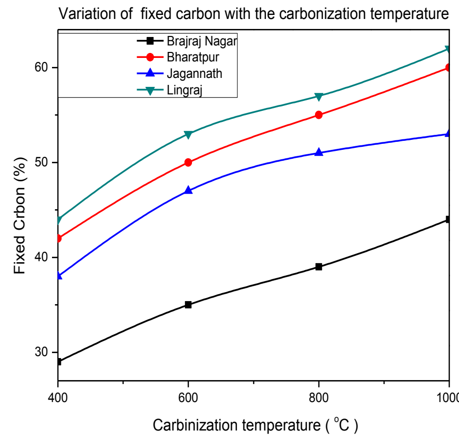
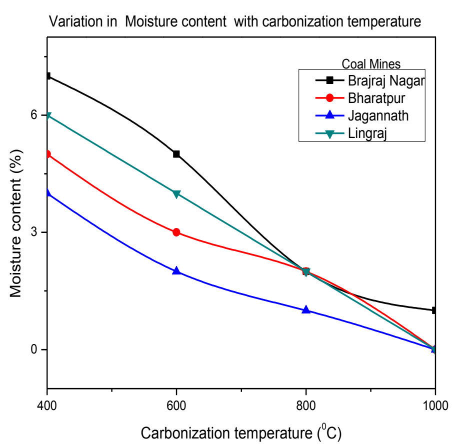


Fig 5.7

Fig 5.8



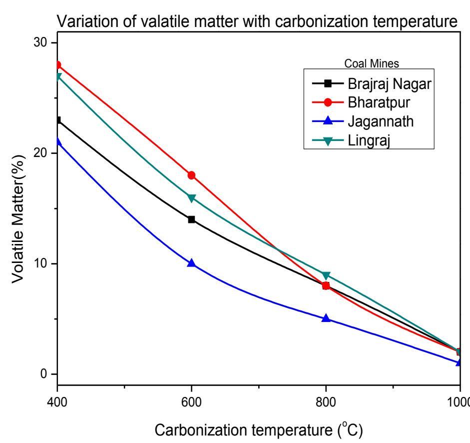


Fig 5.9

fig 5.10

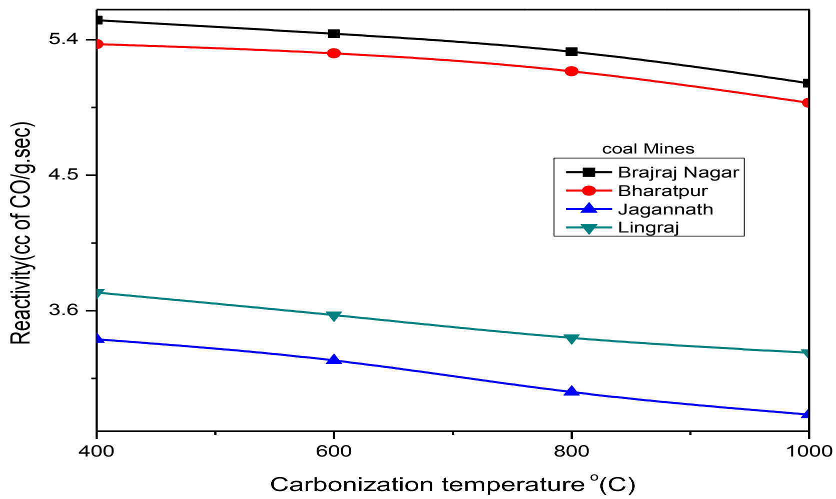


Fig 5.11: Variation of reactivity of the chars with carbonization temperature

5.8 Effect of carbonization temperature on apparent porosity and apparent density:

We studied effect of carbonization temperature on the apparent porosity and apparent density of the coal samples as shown in the table. Apparent porosity increases up to the temperature 400°C because of the formation of pores and voids after that decreases up to the temperature of 1000°C because of the shrinkage in the pores due to rearrangement of carbon matrix. Apparent density decreases up to the temperature of 400°C after that increases up to the temperature of 1000°C

Table 5.8(a): Effect of the carbonization temperature on the apparent porosity and apparent density of Brajraj nagar coalmine:

Carbonization temperature °C	Apparent Porosity (%)	Apparent density
_	36.82	1.32
400	44.77	1.07
600	43.01	1.19
800	41.32	1.24
1000	39.45	1.29

5.8(b): Effect of the carbonization temperature on the apparent porosity and apparent density of the Jagannath coal mine:

Carbonization temperature °C	Apparent Porosity (%)	Apparent density
_	25.28	1.60
400	34.21	1.18
600	32.79	1.33
800	30.19	1.42
1000	29.10	1.51

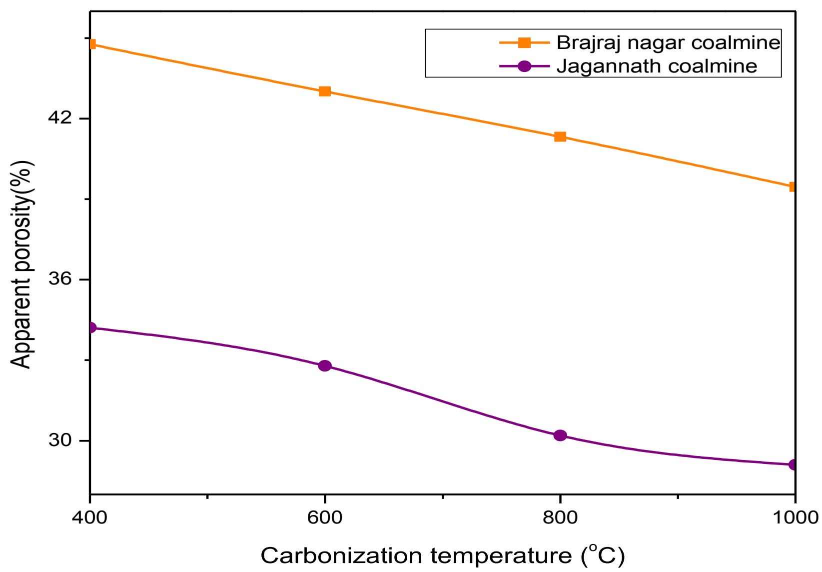


Fig 5.12: Variation of the apparent porosity with the carbonization temperature

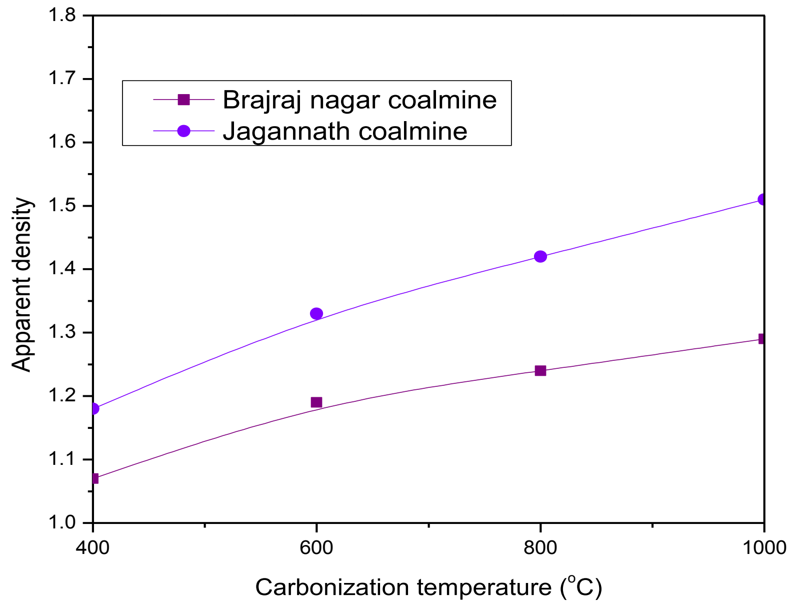


Fig 5.13: Variation of the apparent density with the carbonization temperature

5.9 Effect of soaking time on the properties of coal:

We studied the effect of soaking time on the properties of the coal chars and it was analyzed that fixed carbon and ash content increases slightly while reactivity decreases when soaking time increases from 60-minute to120 minute

Table 5.9: Effect of soaking time on the proximate analysis and reactivity of Brajraj nagar coal samples

Carbonization temperature	Soaking time	Volatile matter (%)	Ash Content (%)	Fixed carbon content (%)	Reactivity (cc of CO/g.sec)
400	1 hr	23	41	29	5.53
600		14	46	35	5.44
800		7	51	39	5.32
1000		2	53	44	5.11
400	2hr	21	44	31	5.44
600		9	49	40	5.32
800		4	52	43	5.12
1000		1	54	45	4.91

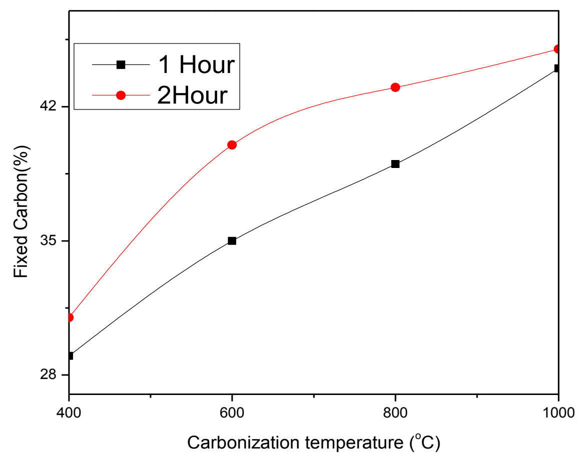


Fig5.14 Variation of fixed carbon with carbonization temperature and soaking time

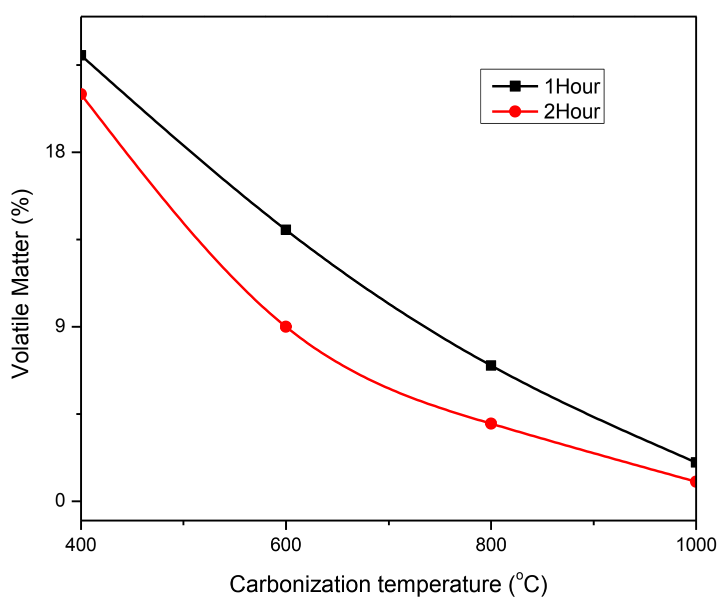


Fig 5.15: Variation of volatile matter with carbonization temperature and soaking time

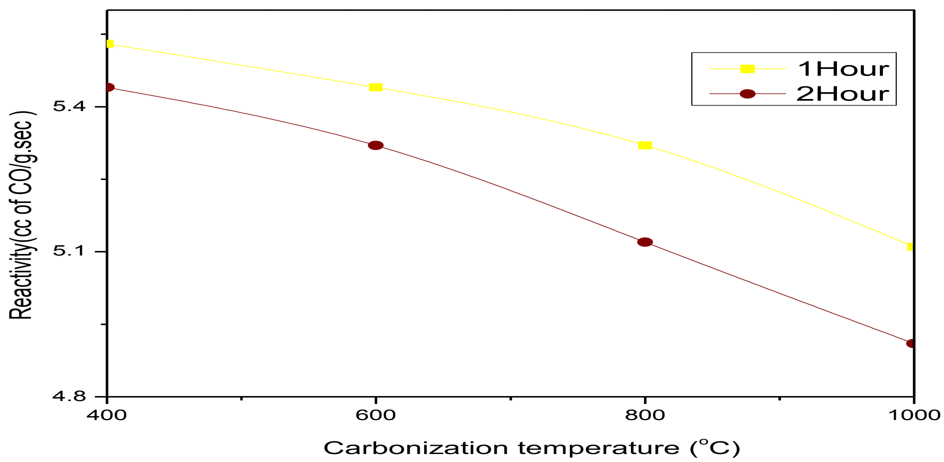


Fig 5.16: Variation of reactivity with carbonization temperature and soaking time

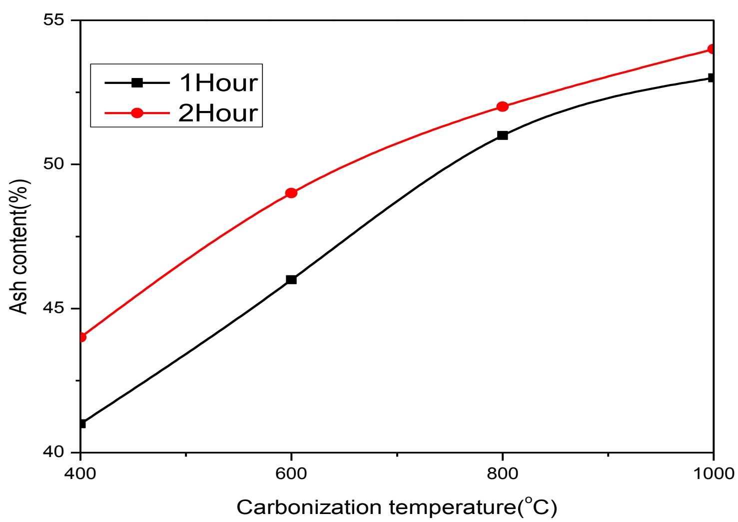


Fig 5.17: Variation of Ash content with carbonization temperature and soaking time

5.10 Effect of different heating rate:

We were studied the effect of the slow(10°C/min) and high(20°C/min) heating rate on the coal chars and it was observed that the slow heating rate provides more carbon yield as compare to the fast heating rate because in slow heating rate the deposition of paralytic carbon is more as compare to fast heating rate. In fast heating rate volatile matter remove very quickly from the coal hence the deposition of carbon is very less while in slow heating rate volatile matter stay for longer time inside the coal due to this reason volatile matter takes part in the cracking process hence deposition of high quantity of carbon as compare to the fast heating rate. High heating rate provides higher porosity as compare to slow heating rate because of the formation of cracks, voids and deposition of low paralytic carbons in the pores. Also higher heating rate provides higher reactivity because the formation of pores and voids at high heating rate.

Table 5.10 (a): Effect of carbonization temperature with slow heating rate on the proximate analysis of Brajraj nagar coalmine.

Carbonization temperature (°C)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)
400	23	41	29
600	14	46	35
800	8	51	39
1000	2	53	44

Table 5.10(b): Effect of carbonization temperature with high Heating rate on the proximate analysis of Brajraj nagar coalmine

Carbonization temperature (°C)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)
400	21	42	31
600	10	47	38
800	2	52	43
1000	1	53	45

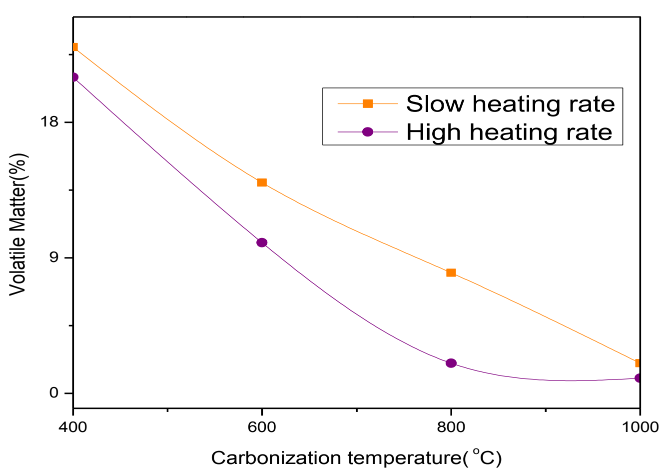


Fig 5.18: Variation of volatile matter with combined effect of carbonization temperature and heating rate

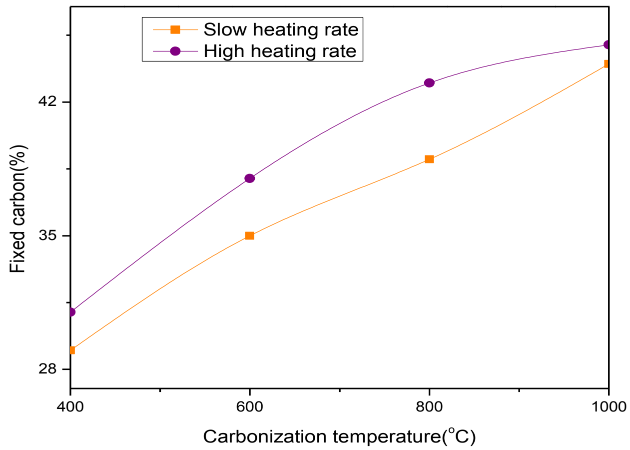


Fig 5.19: Variation of Fixed carbon with the combined effect of carbonization temperature and heating rate

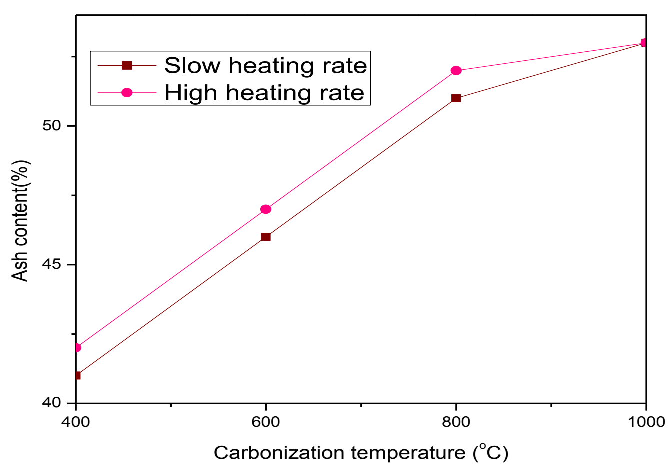


Fig 5.20: Variation of Ash content with the combined effect of carbonization temperature and heating rate

5.11 Useful heat value:

Gradation of non-coking coal is based on the useful heating value (UHV). The UHV calculated for high moisture content, i.e. greater than 2% by the following formula

UHV Calculated by = 8900 – 138(%A+%M)[28]

Table 5.10: Useful heat value

Mines name	Useful heat value Kcal/kg	Grades
Brajraj nagar	2414	F
Bharatpur	4898	D
Basundhara	3932	E
Lingraj	4898	D
Jagannath	3242	F

Chapter 6

Conclusions

Conclusions:

In the present project work on the basis of above experiments and results the following investigation were concluded

1. Proximate analyses of all coal samples were calculated and it is observed that Lingraj and Bharatpur coal mines characteristics matches with the coal specification for the DRI Plant.
2. It is observed that all the selected coal samples showed high ash fusion temperature, and this avoided the problem of ring formation inside the rotary kiln occurring due to low AFT.
3. Except Basundhra coalmine, remaining coalmines showed no caking qualities.
4. It is observed that all the selected coal samples showed high reactivity, which met the requirements of DRI plants. In general, coal with high reactivity is preferred because high reactivity allows kiln operation at low temperature, which increases the kiln productivity and lowers kiln temperature automatically decreasing the tendency of ring formation.
5. As the carbonization temperature increases from 400°C to 1000°C, Fixed carbon content and ash content increased while volatile matter decreased.

6. As the carbonization temperature increases from 400°C-1000°C, reactivity of the coal chars decreased towards the carbon dioxide.
7. Apparent porosity initially increases up to 400°C and after that decreases as the carbonization temperature increases from 400°C to 1000°C. Apparent density has the contradictory effect of apparent porosity.
8. We studied the effect of soaking time on the coal char properties and it was observed that fixed carbon and ash content increases to some extent, while reactivity decreases when soaking time increases from 60-minute to120 minutes.
9. Analyzing the effect of heating rate on the char yield and it is observed that char yield decreases with high heating rate.

Chapter 7

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